Sampling in Ice Clouds

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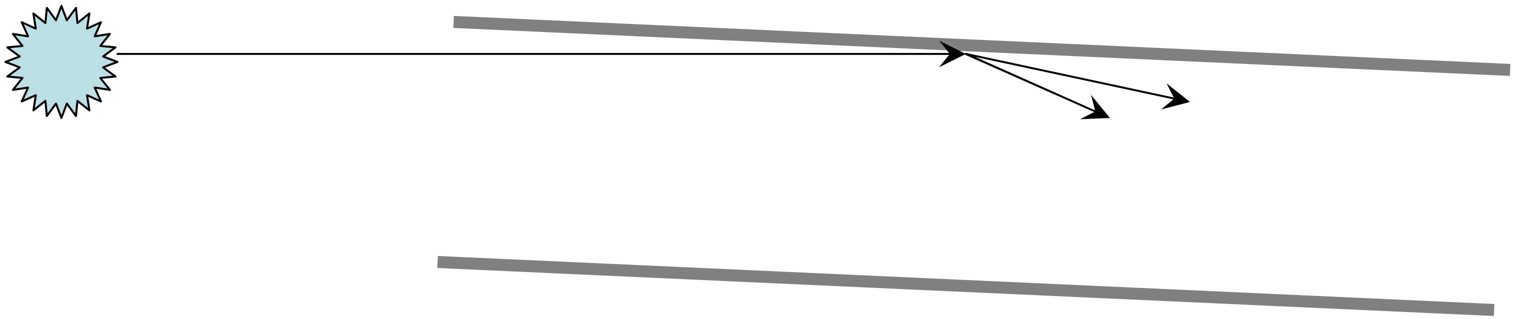
also: D. Cziczo, P. Hudson, M. Schein, D. Thomson

CRYSTAL-FACE Workshop 2003

The problem:



When it bounces, ice can "sandblast", shatter, acquire coating, ….

Sticking is unlikely for velocity > 1 m s^{-1}.

It can't completely melt! (insufficient kinetic energy)

Many (10 ??) bounces possible.

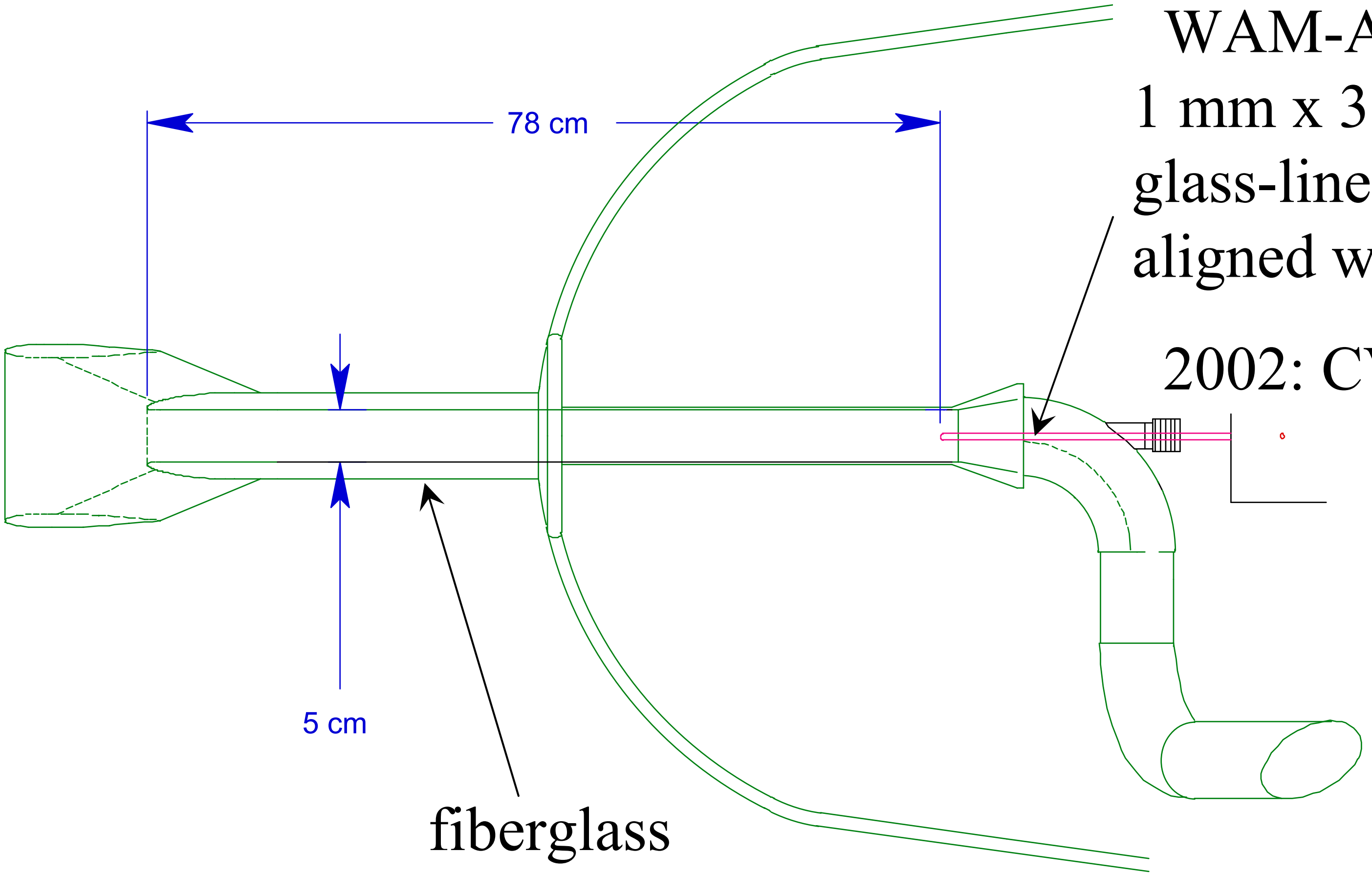
Length and time scales (spherical ice, 190 m s^{-1}, 120 mbar)

Diameter (µm)	L_{stop} (cm)	$\tan^{-1}(5mm/L_{stop})$ (degrees)	(Grav. fall speed) x (evap. time @ 20°C)
5	1.3	21	25 µm
25	14	2	1.3 cm
100	90	0.3	3 m

≈ inlet alignment requirement.
B57 pitch varies by ~3° in "level" flight

- Large cirrus crystals have moderate Reynolds numbers at aircraft velocity (calculations here include a 1st order correction)
- (L_{stop} approx. linear in v, less than linear in air density)

PALMS inlet designs



WAM-ACCENT:
1 mm x 30 cm
glass-lined capillary
aligned within 3°

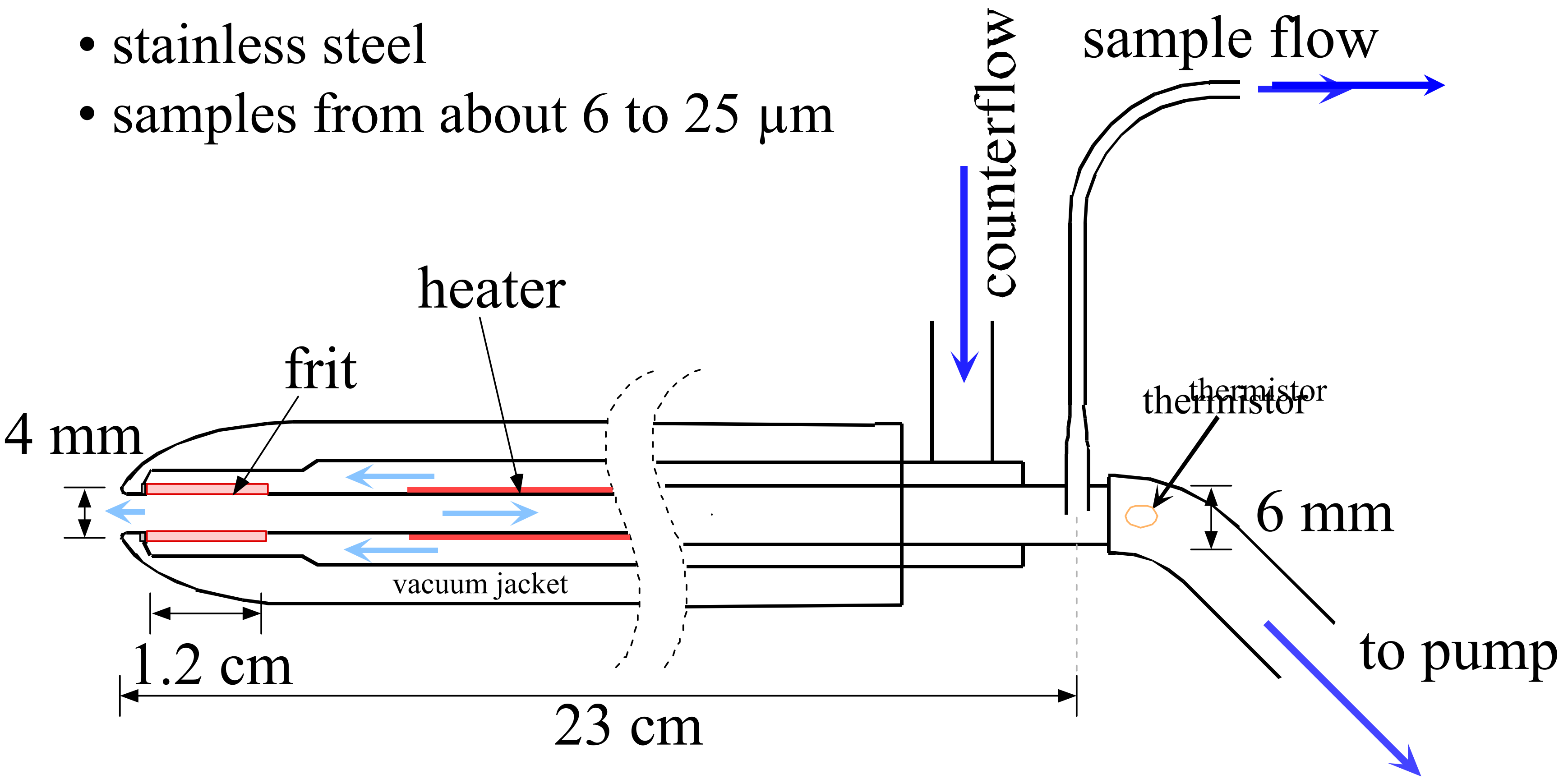
2002: CVI …

Even fairly large ice crystals should be aligned with duct

Counterflow Virtual Impactor (CVI) design

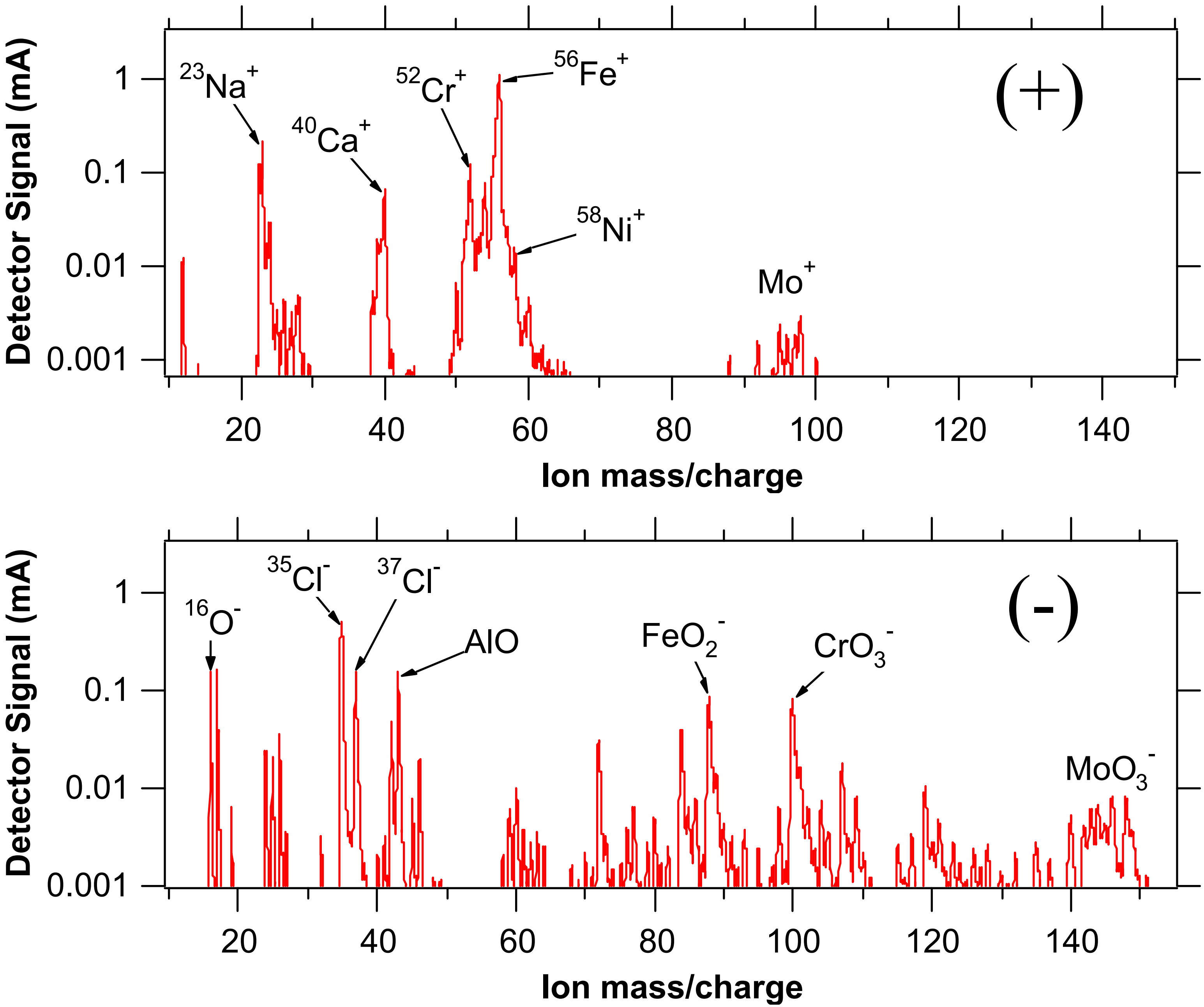
based on Laucks and Twohy with shorter frit, slightly smaller diameter

- stainless steel
- samples from about 6 to 25 μm

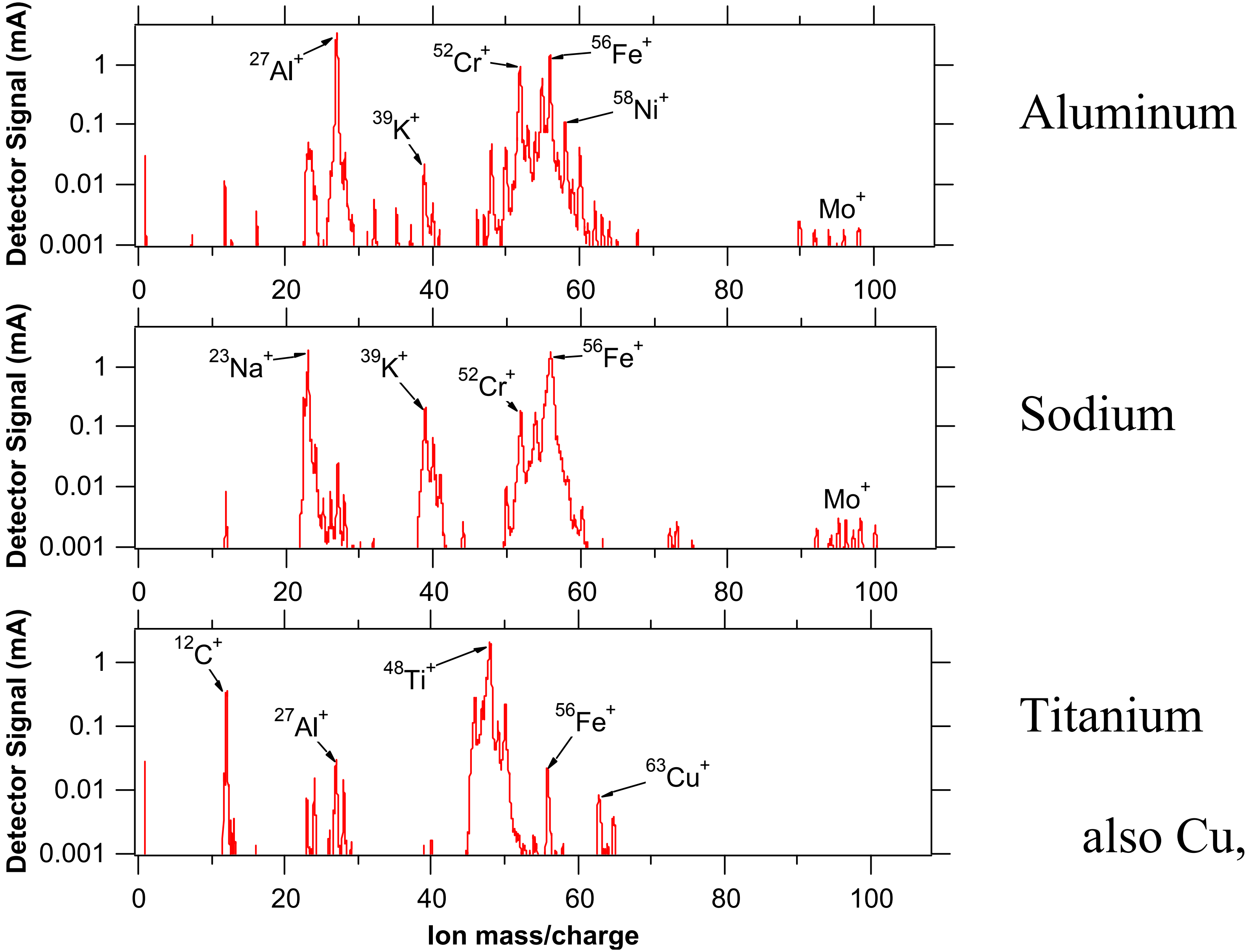


Laucks, M. L., and C. H. Twohy, *Aerosol Sci. Technol.*, **28**, 40, 1998.

Typical metal spectra:

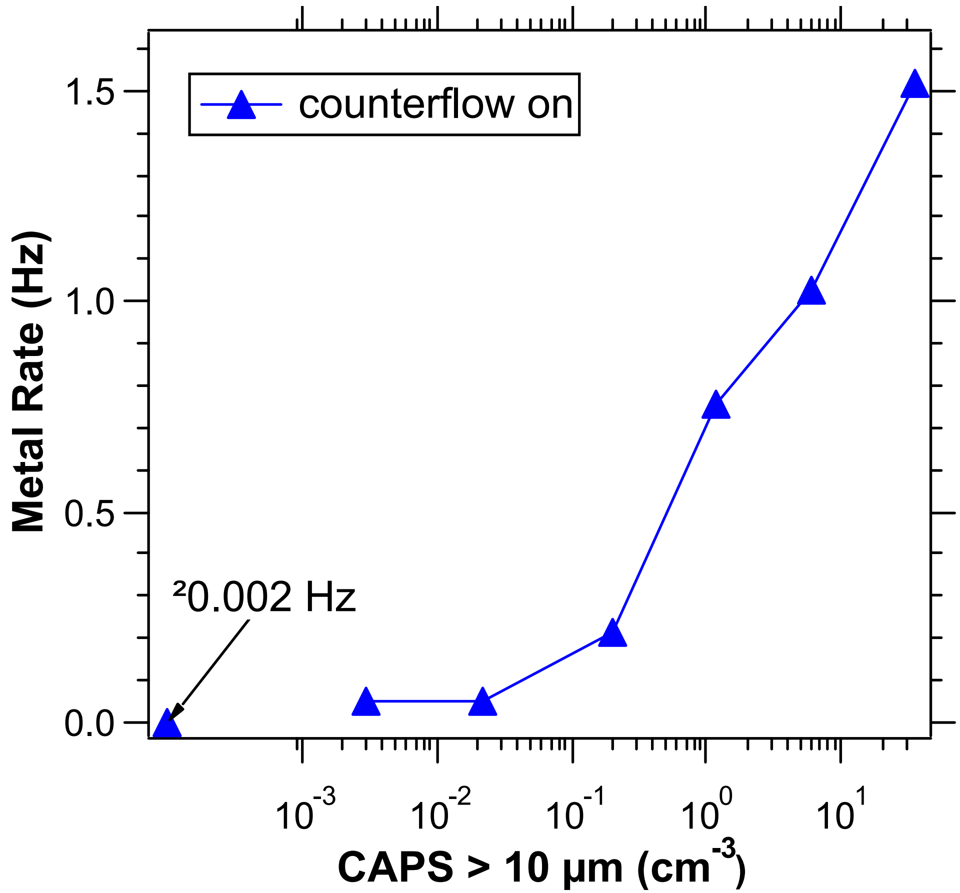


Variations:



also Cu, …

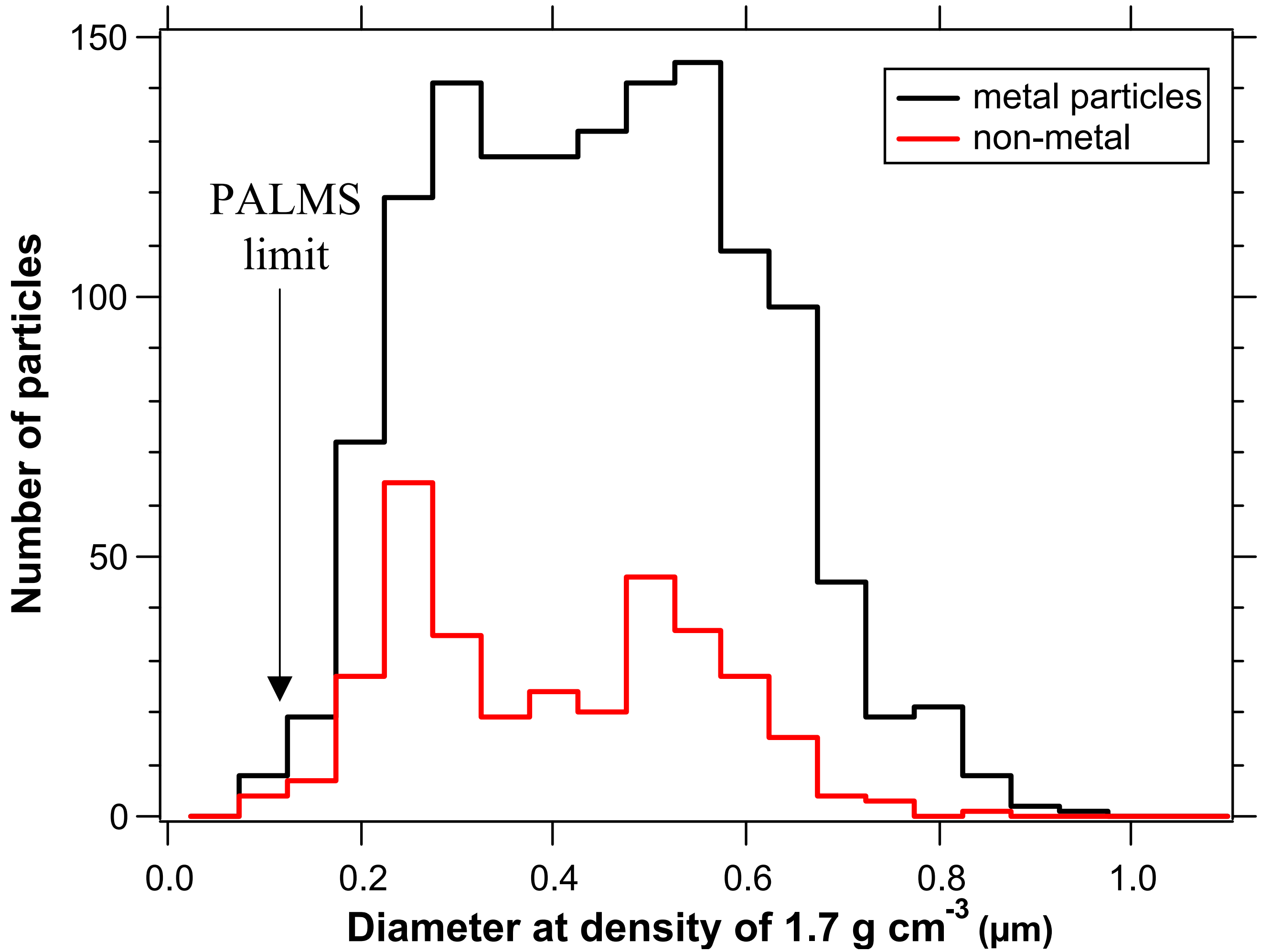
Frequency of metal particles



~90% of spectra in cloud contained metal

Excludes 709: intermittent CAPS detection of thin cloud, 711-719: PALMS noise affected rates

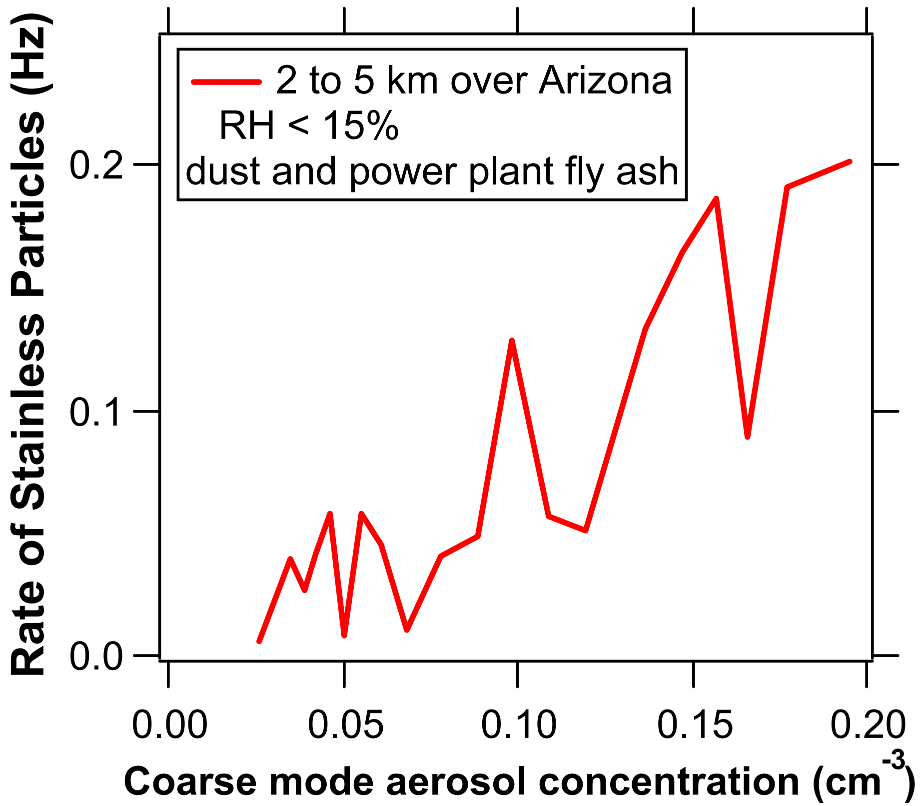
Size of metal particles



Uses new aerodynamic sizing

Size is smaller than grain size of steel => uniformity?

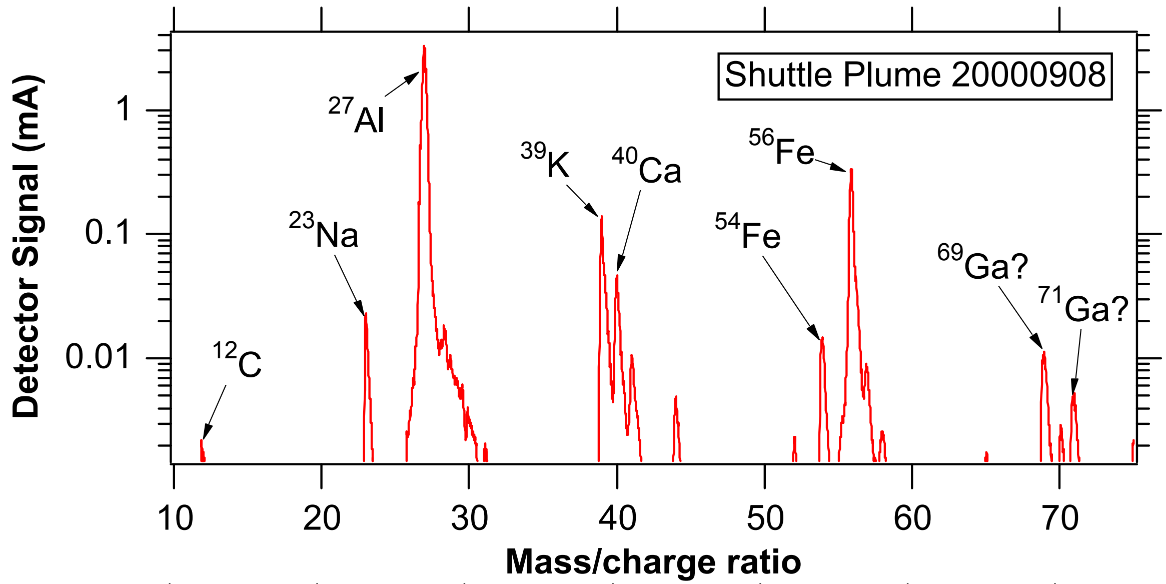
Dust also creates stainless steel particles



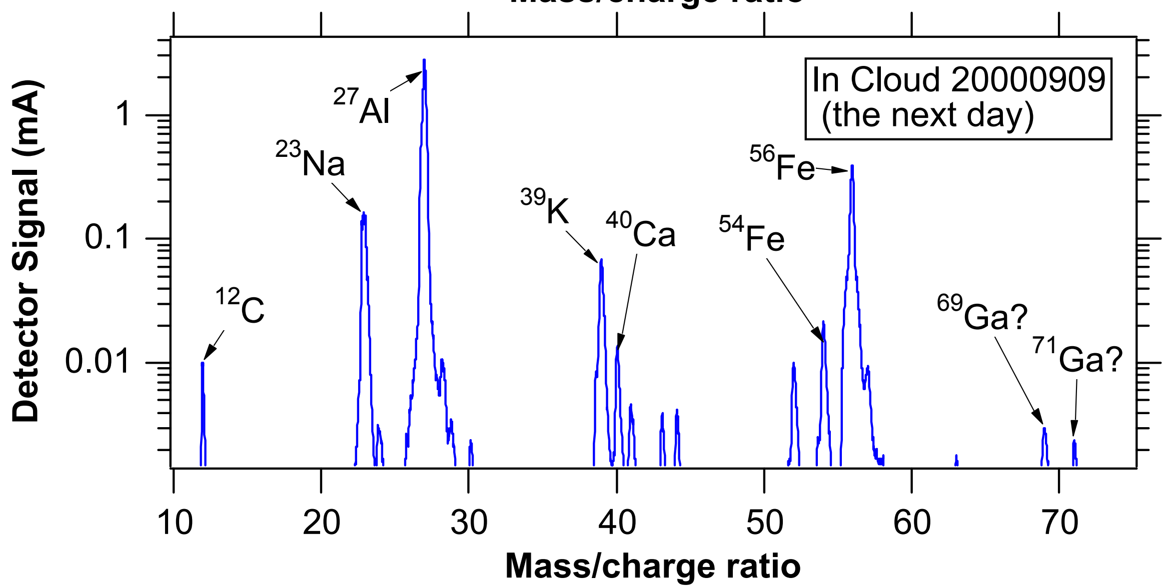
Mass spectra of these metal particles are similar to metal particles from ice clouds.

- PALMS flew in a wing pod on the NOAA P3 in spring 2002
- The same inlet hardware as on the B57 in CRYSTAL-FACE (shroud, duct, CVI inlet)

Previously deposited particles:

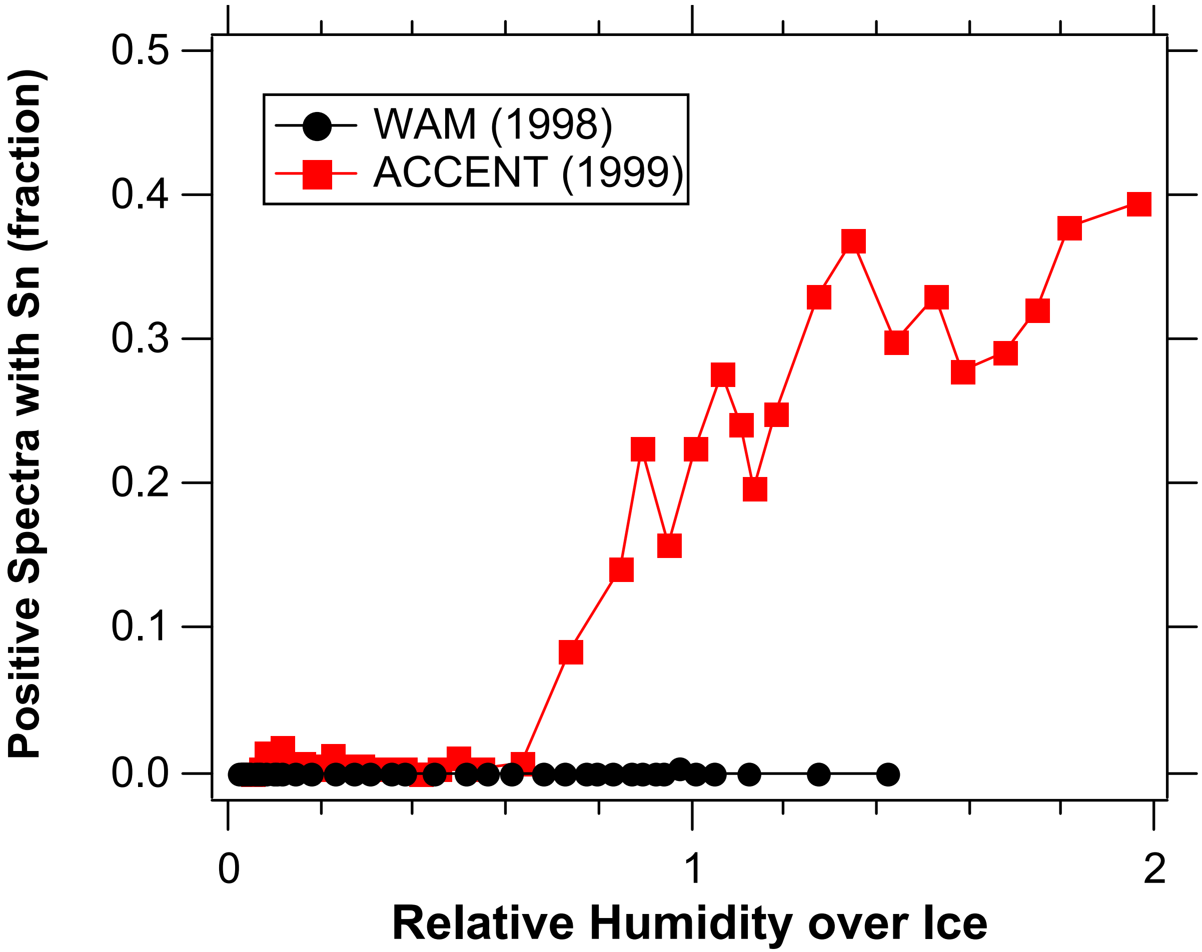


In the space shuttle plume



In cloud, the next day!

More wall effects: tin



Above 11 km,
0-35° N

Hypothesis: Inlet was clean during WAM, contaminated with Sn during ACCENT (by soldering near inlet)

Previous and future PALMS data?

- *Papers* use data from out of cloud and clean WAM inlet
  => should be no significant problems

- Some possibly good data will be lost:
  - real metal particles in clouds

- We think we still have good data with uncontaminated particles during CRYSTAL/FACE (-> Cziczo talk)

Other Groups *(my comments)*

Heintzenberg et al., 1996: CVI, Electron microscope analysis
cirrus clouds
~75% residues had high Fe content
explained as crustal, *although only 25% also had Si*

Petzold et al., 1998: CVI, Electron microscope analysis
Falcon, both cirrus clouds and contrails
residues < 1 μm mostly black carbon
residues > 1.5 μm mostly stainless steel
contrail: ≥ 50% of mass in metals, attributed to engine wear
ratio to black carbon would imply order 1 ton/yr engine wear

Noone, K. B., K. H. Noone, J. Heintzenberg, J. Ström, and J. A. Ogren, *J. Atmos. Oceanic Technol.*, **10**, 294, 1993
J. Heintzenberg, K. Okada, and J. Ström, *Atmos. Res.,* **41**, 81, 1996,
Petzold, A., J. Ström, S. Ohlsson, and F. P. Schröder, *Atmos. Res.,* **49**, 21, 1998.

Twohy and Gandrud 1998: CVI, electron microscope
DC8, contrails

- "Metals"   12 - 36% of residues, typical size 0.4 μm
- "Minerals"   30 - 50% of residues, typical size 0.9 μm

Fe particles classified as "mineral"

Twohy, C. H., and B. W. Gandrud, *Geophys. Res. Lett.*, **25**, 1359, 1998.

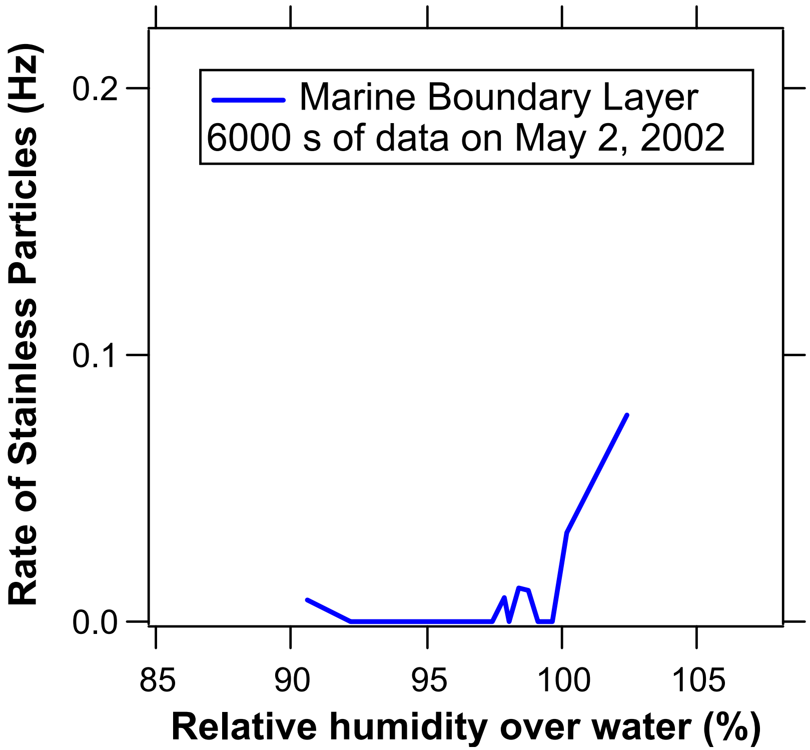
Other measurements:

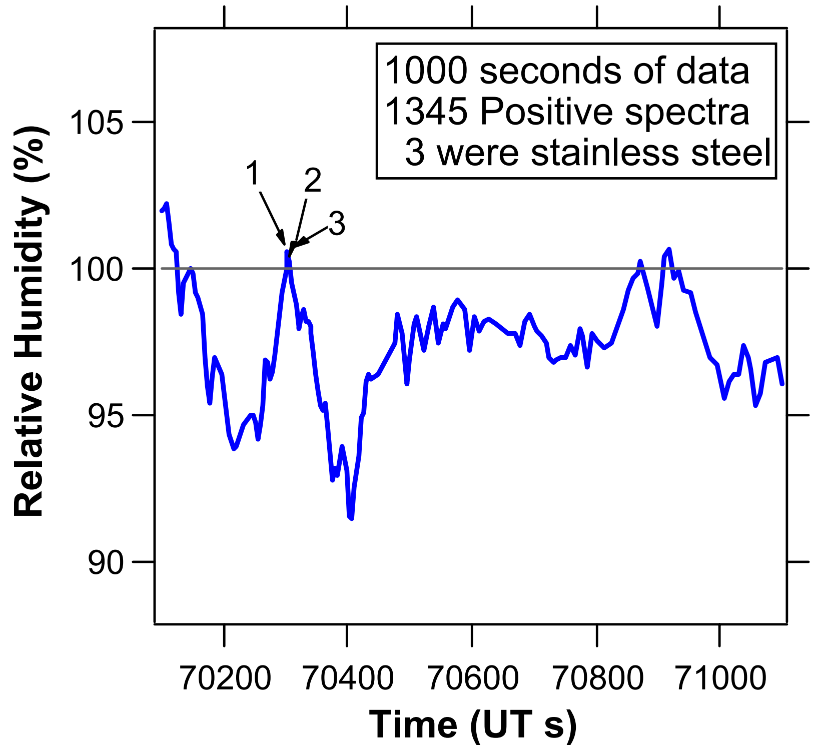
- *Everybody* with a CVI has seen metals at significant rates ($\geq$ 10%) but usually less than PALMS (90%).

- Higher rate for PALMS not understood
  PALMS more sensitive to metals?
  Subtle design differences (e.g. shorter frit)?
  Sampling efficiency for different sizes?

- Two CRYSTAL-FACE experiments:
  DU/Arizona State: frequent zinc in ice clouds
  CVI on Citation
  -> See their presentations

Fast response data are helpful:





Suppose: 3 steel particles were found in a 15 minute filter sample near California coast and shipping lanes?

Could the metal particles be real?

Pro:

- Sheridan et al. found order 1% metal particles in upper trop.
- Metal particles can be good ice nuclei.

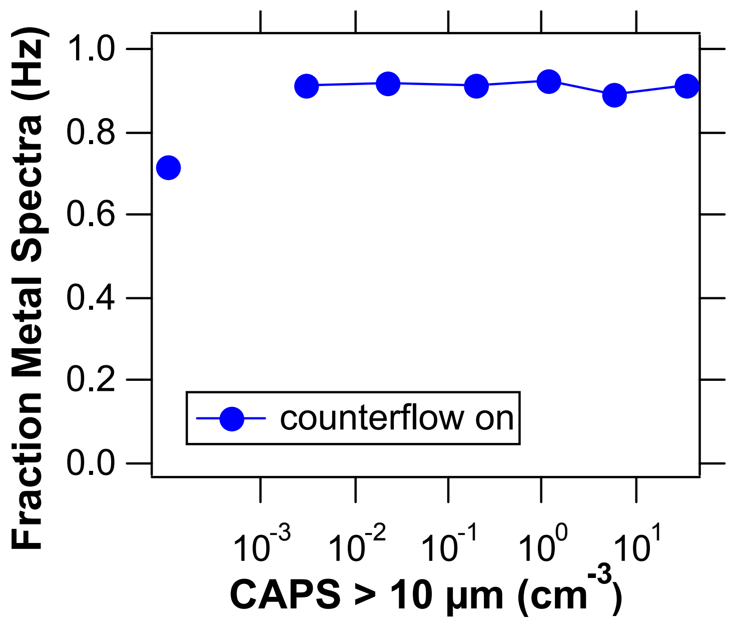
Could the metal particles be real?

Con:

- Requires a large source of metals to free troposphere:
  1 per liter, 0.5 µm, Northern Hemisphere, 2 week lifetime
  => 13000 tons/year

- Why stainless steel? (found by both PALMS and Ström et al.)

  - Proportion of metal particles stays high even above 1 cm^{-3} ice



Are the metal particles inlet contamination?

Pro:

• Unambiguous correlations of metals with presence of ice or dust.

Con:

• Metals don't always match inlet composition.

Notes:

• Chlorine? *Involved in corrosion of stainless steel.*

• Shouldn't the entire front of the airplane be eroded?
Probably not easy to observe:
100 l^{-1} ice, abrade 0.5 μm chunks => 1 μm in 100 hrs in cirrus

Summary

- On a high speed aircraft, ice crystals larger than about 25 μm *will* hit the wall of an inlet, either due to inertia or gravity.

- Published aircraft data on cirrus/contrail ice residues have found substantial numbers (>10%) of metal particles. They cannot be distinguished by size alone.

- Ice crystals can knock pre-existing particles off the wall of an inlet. Ice crystals appear to be able to abrade stainless steel.

- Some real metal particles are possible. However, to explain published CVI data the global flux would be very substantial.

- Abrasion/shattering may be frequent enough to affect data on ice number, especially if knocking older particles off the wall. Water content should be OK.

Suggestions:

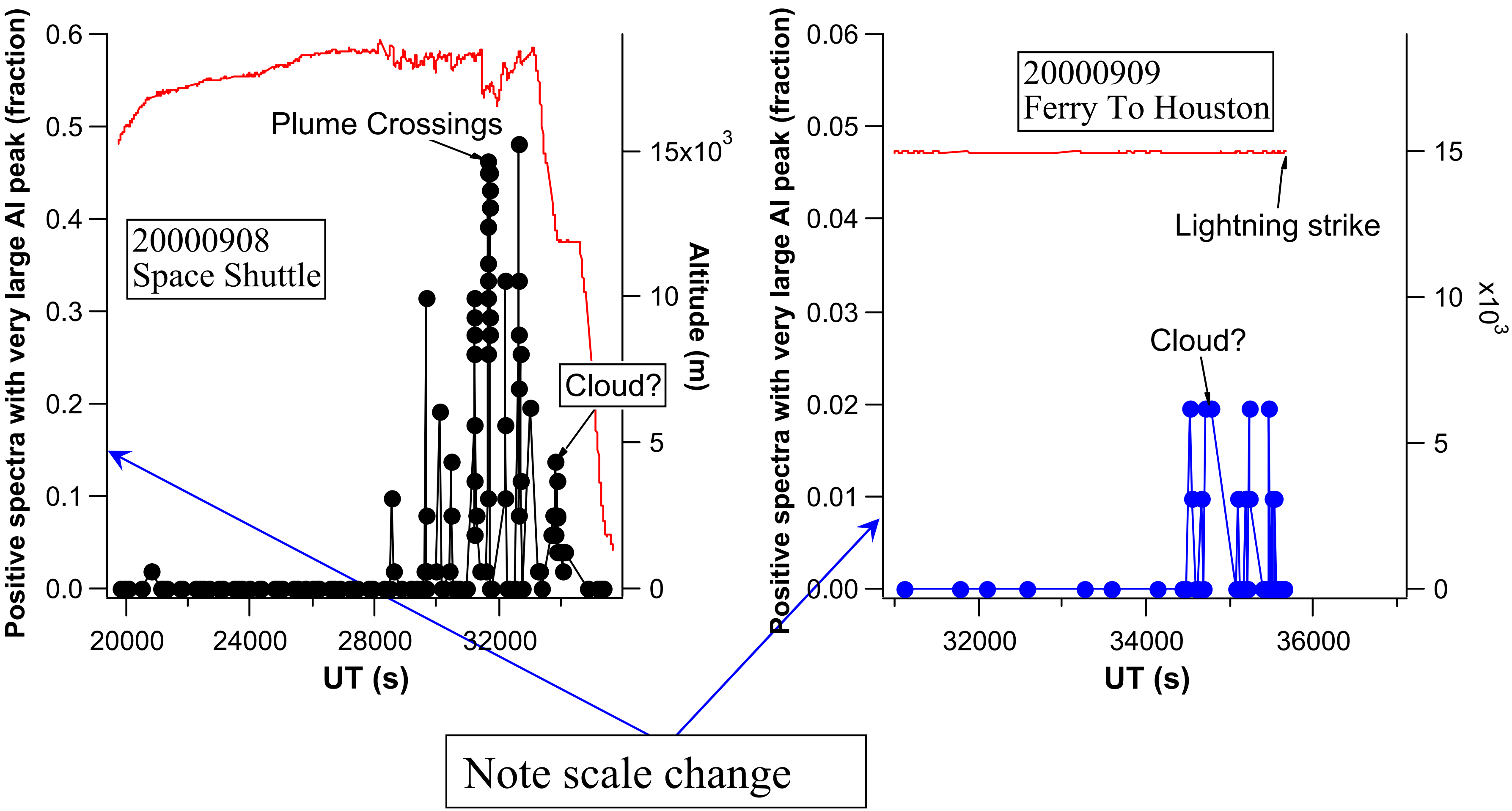
- Lab experiments on ice particles hitting steel

- Gold plate the inlet for a unique signature

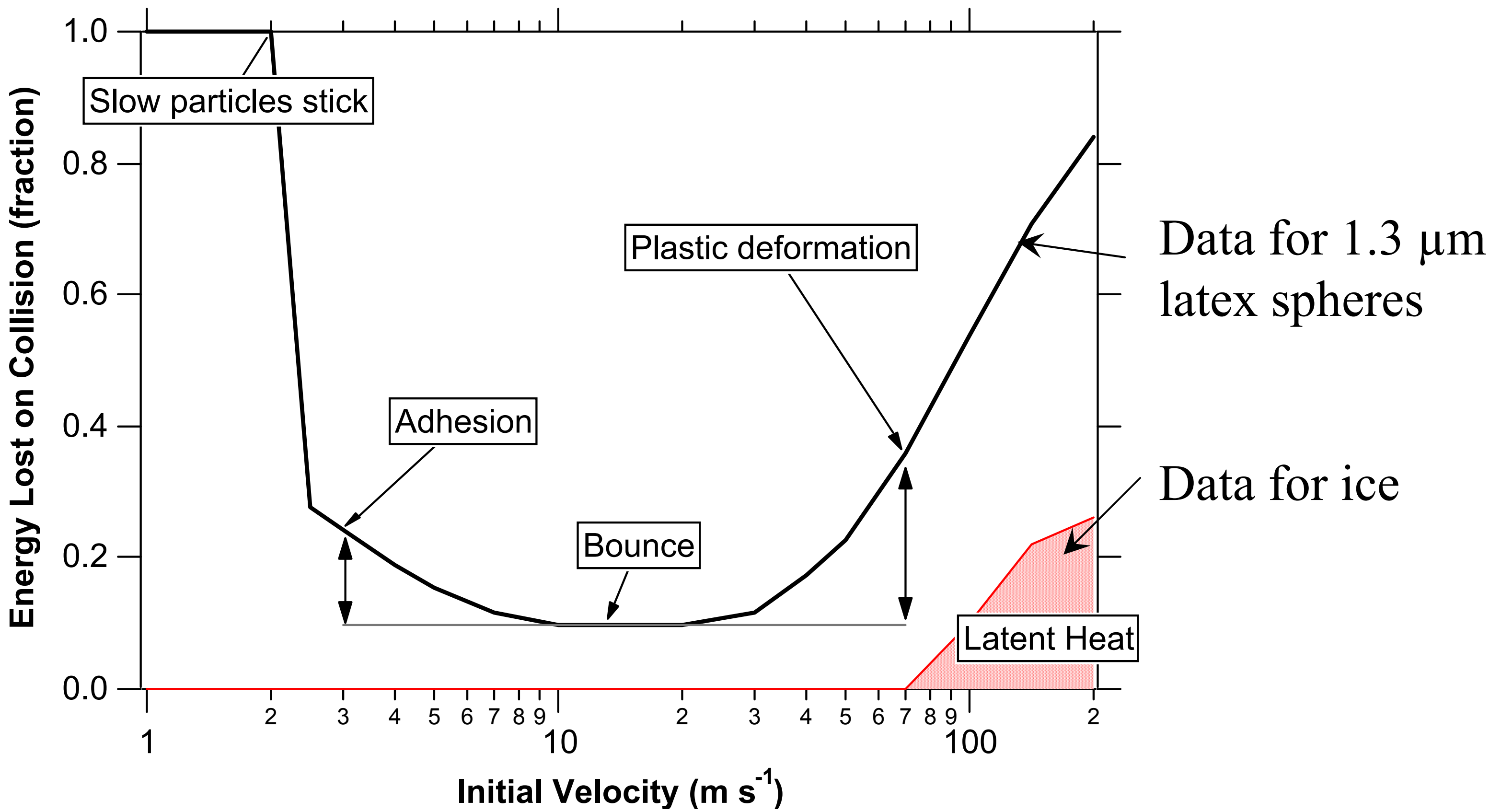
- Fly in the Southern Hemisphere for less industrial influence.

- Explore "shadowed" forward-facing inlets to exclude the largest particles that always hit a wall.
 (e.g. different version of ER2 football)

Can ice knock particles off an inlet wall?



Energetics of wall collisions:



- **Larger (e.g. cirrus) particles stick only at < 1 m s^{-1}**
- **Many (~10) bounces energetically feasible**
- **100 m s^{-1} collision has more energy than 100 story drop**

Dahneke, B., *Aerosol Sci. Technol.,* **23**, 25, 1996.
Sugi, N., M Arakawa, M. Kouchi, and N. Maeno, *Geophys. Res. Lett.,* **25**, 837, 1998.